BELLCOMM, INC.
1100 Seventeenth Street, N.W. Washington, D.C. 20036

SUBJECT: A Method of Navigating on and near the Moon - Case 340

DATE: June 28, 1968

FROM: D. B. James

ABSTRACT

A method of navigating at lunar distances is developed which depends on differential ranging to two lunar stations from a triplet of MSFN stations on earth. The method can easily be applied to the case of navigating a lunar roving vehicle or flying unit relative to its parent spacecraft. In conjunction with on-board CSM navigation using landmarks, the method could also be used to navigate an LM to high gate allowing the major errors to be removed while the engine is operating efficiently.

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MEMORANDUM FOR FILE

INTRODUCTION

A method of navigating relative to a fixed lunar based station is developed based on Manned Spaceflight Network's (MSFN's) Unified S-Band System (USB). The method can be readily applied to the case of a roving vehicle or a lunar flying vehicle moving away from its parent spacecraft. In addition, the method can also be used to provide differential navigation inputs to a landing Lunar Module (LM) where the orbiting Command and Service Module (CSM) replaces the original fixed lunar based station. In this latter case, if the CSM can see the LM landing point (or other landmarks) and determine its own position relative to the landing site, downrange and crossrange errors can be calculated and transmitted to the LM to correct its trajectory during the main powered burn.

METHOD

Use is made of the USB system with slight modification of the existing equipment at the 85 and 30 foot MSFN stations.

Ranging signals are transmitted from the 85 foot dish (A) to transponders on the fixed lunar station O and to the mobile lunar station P (see Figure 1). Either the same signal can be sent to both stations or different frequencies can be used, however, the signals must be generated from the same master clock and Pseudo Random Number generator.

At the 30 foot slave stations (B and C) receivers tuned to the turn around frequencies of transponders O and P are used. One signal, say that from the fixed O station, is used in place of a station clock with the result that the tracked signal generates the path difference (AOB - APB) between the Master Station A, the two stations on the moon, and the satellite station B.

Similarly at the Master Station, one signal is used to replace the master clock and the differential round trip range AOA - APA is determined.

ANALYSIS

Define a coordinate system centered on the fixed station O with the line joining O and the 85 foot dish at A defining the z azis. Choose arbitrary x and y axes. Let the coordinates of the mobile station P be x_p, y_p, z_p. Let the coordinates of the 85 foot station A be O, O, R. Let the coordinates of the 30 foot station B be x_b, y_b, $R + z_b$. Then

$$AO = R$$

$$BO = \sqrt{\left[x_b^2 + y_b^2 + (R + z_b^2)\right]} \simeq R + \frac{\frac{1}{2} r_b^2}{R} + z_b$$

where $r_b^2 = x_b^2 + y_b^2 + z_b^2$

$$AP = \sqrt{\left[x_p^2 + y_p^2 + (R - z_p)^2\right]} \simeq R + \frac{\frac{1}{2} r_p^2}{R} - z_p$$

where $r_p^2 = x_p^2 + y_p^2 + z_p^2$

$$BP = \sqrt{\left[(x_p - x_b)^2 + (y_p - y_b)^2 + (z_p - R - z_b)^2\right]}$$

$$\simeq R + \frac{\frac{1}{2} r_b^2}{R} + \frac{\frac{1}{2} r_p^2}{R} - \frac{\Sigma x_p x_b}{R} - z_p + z_b$$

The round trip range to the fixed station O measured from A gives us 2R.

The differential range to O and P measured from A gives AOA - APA

$$= 2z_p - \frac{r_p^2}{R} = 2z_p \text{ for small } r_p.$$

The differential range from A to O and P and back to B gives AOB - APB

$$= 2z_p - \frac{r_p^2}{R} + \frac{\sum x_p \; x_b}{R}$$

or the difference between the differential ranges measured at stations A and B

$$= \frac{\sum x_p \; x_b}{R}$$ i.e., the dot product of the vectors

$\bar{r}_p$ and $\bar{r}_b$ divided by the range R.

ACCURACY

Normal use of the ranging system results in an accuracy of about 1 meter. Thus we can measure z_p to about one meter. x_p and y_p can be measured to $\frac{R}{x_b}$ meters.

Since the earth moon distance is about 250,000 miles and the station separation AB is about 1,000 miles x_p and y_p can be measured to about 250 meters.

If one wishes greater accuracy and is prepared to use additional equipment to count cycles then one can measure z_p to 10 cms and x_p and y_p to 25 meters accuracy. In this latter case transponder turn around delay would be quite critical but can be calibrated since both stations are together at the beginning of the mission.

APPLICATION TO LM DESCENT

In order to explore the moon in a meaningful way, it is necessary to land at a number of sites which will be considerably rougher than those chosen for the initial landings. In addition, because the astronauts will have limited mobility, it will be necessary to land much more accurately than Apollo.

In many cases the rougher approach will require steeper flight path angles with higher ΔV penalties which in turn will demand that the ΔV allocated to redesignation be reduced. If the errors can be removed while the engine is operating efficiently in the main powered burn, one can arrive at high gate on target for little additional cost. This requires accurate navigation prior to the initiation of the main powered burn as well as during the burn.

Using the scheme described before with the CSM acting as the station O and the LM as the station P, we can perform differential navigation of the LM against the CSM and compare the measurement to prediction and determine the difference.

Using the on-board optical navigation system, the CSM pilot can navigate relative to either the landing site or other landmarks and again compare measurement with prediction and determine the difference. Adding these two differences together gives an estimate of the error in landing the LM would make if it were not corrected.

Since the LM landing radar is capable of altitude measurement it may be only necessary to transmit an earth computed crosstrack and downtrack correction to be used by the LM computer in retargeting high gate.

Using the accuracy estimates generated earlier it would appear that one could navigate to high gate to an accuracy of about 250 meters using the ranging system as is. Greater accuracy would require slightly different counting equipment at the MSFN stations.

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D. B. James

Attachment
Figure 1

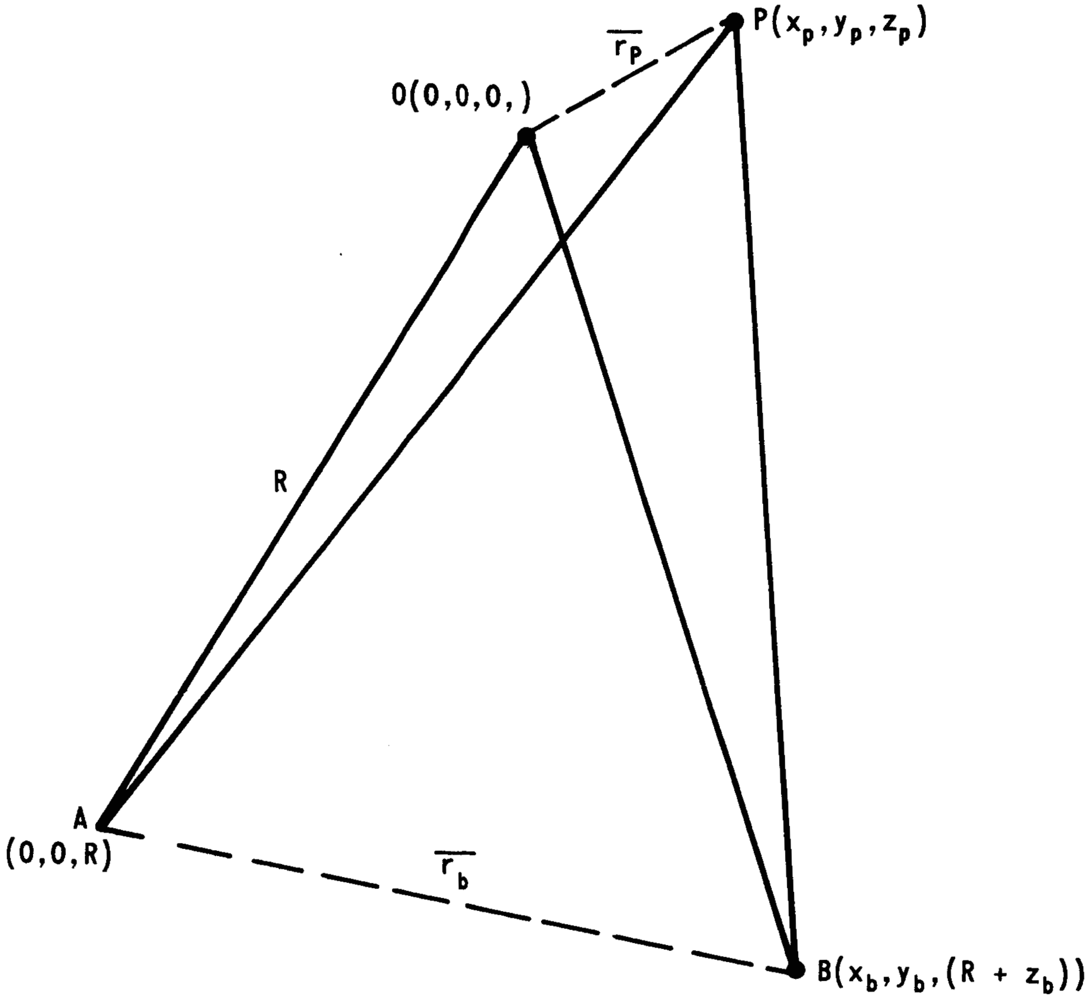

FIGURE I - COORDINATE SYSTEM WHERE O IS THE FIXED LUNAR STATION, P IS THE MOBILE LUNAR STATION, A IS THE MASTER 85' STATION AND B IS THE SATELLITE 30' STATION

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